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(54) **NANOENGINEERED THERMAL MATERIALS BASED ON CARBON NANOTUBE ARRAY COMPOSITES**

6,231,744 B1 5/2001 Ying et al.
6,340,822 B1 1/2002 Brown et al.

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(Continued)

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FOREIGN PATENT DOCUMENTS

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OTHER PUBLICATIONS

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Banerjee, Kaustav, et al., "3-D Heterogeneous ICs: A Technology for the Next Decade and Beyond", *5th IEEE Workshop on Signal Propagation on Interconnects*, Venice, Italy, May 13-16, 2001.

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(52) **U.S. Cl.** **165/185; 165/80.3**

(58) **Field of Classification Search** **165/185, 165/80.3; 361/704**

See application file for complete search history.

(57) **ABSTRACT**(56) **References Cited**

U.S. PATENT DOCUMENTS

- 4,485,429 A * 11/1984 Mittal 361/718
5,316,080 A * 5/1994 Banks et al. 165/185
5,725,707 A * 3/1998 Koon et al. 156/157
5,818,700 A * 10/1998 Purinton 361/760
5,837,081 A * 11/1998 Ting et al. 156/89.26
5,898,570 A * 4/1999 Koon et al. 165/185
5,926,370 A 7/1999 Cromwell
5,965,267 A 10/1999 Nolan et al.
6,156,256 A 12/2000 Kennel

A method for providing for thermal conduction using an array of carbon nanotubes (CNTs). An array of vertically oriented CNTs is grown on a substrate having high thermal conductivity, and interstitial regions between adjacent CNTs in the array are partly or wholly filled with a filler material having a high thermal conductivity so that at least one end of each CNT is exposed. The exposed end of each CNT is pressed against a surface of an object from which heat is to be removed. The CNT-filler composite adjacent to the substrate provides improved mechanical strength to anchor CNTs in place and also serves as a heat spreader to improve diffusion of heat flux from the smaller volume (CNTs) to a larger heat sink.

30 Claims, 7 Drawing Sheets

